

# Experiences of Wet Type Electrostatic Precipitator Successfully Applied for SO<sub>3</sub> Mist Removal in Boilers Using High Sulfur Content Fuel

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## ABSTRACT

In thermal power plants, especially using high sulfur content fuel, much attention is recently paid to SO<sub>3</sub> emission, because gaseous SO<sub>3</sub> in flue gas is condensed to sulfuric acid mist (SO<sub>3</sub> mist) in the wet type FGD, which is installed to meet SO<sub>2</sub> emission regulation. SO<sub>3</sub> mist is very fine under-sub-micron sized particulate matter (PM), which is very visible even if the concentration is relatively low, and causes air pollution. SO<sub>3</sub> is often recognized as a part of the total SO<sub>x</sub>. However, recently, discussion comes out, especially in the United States, that the condensed SO<sub>3</sub> mist should be included in the total dust instead of SO<sub>x</sub> and regulated together with solid dust. In order to remove SO<sub>3</sub> mist from flue gas, wet type electrostatic precipitator (WESP) installed in the horizontal gas flow at downstream of FGD (Flue Gas Desulfurization System) is one of the best solutions and the most proven technology at this moment. This paper describes the experiences of WESP successfully applied in Japan and Europe, and also shows the advantages of the technology. Measuring method of solid dust and SO<sub>3</sub> concentration is a very important issue for WESP application, which is discussed in this paper as well.

## 1. INTRODUCTION

When high sulfur contained fuel is burned in boiler furnace, sulfur content in fuel is combined with oxygen and mainly forms gaseous SO<sub>2</sub>, but some of the content is furthermore oxidized to gaseous SO<sub>3</sub>. When SCR is equipped in the plant, the conversion rate from SO<sub>2</sub> to SO<sub>3</sub> increases because additional SO<sub>3</sub> is converted from SO<sub>2</sub> by catalytic effect of SCR. The conversion rate depends on various plant conditions, but it may typically be around 2 - 3 % in coal fired boiler plant, and around 5 - 6% in oil fired boiler. In oil fired boiler, and boiler using fuels with similar characteristics such as petro-cokes, asphalt, orimulsion, etc., heavy metal components contained in ash adhered on the surface of boiler tubes will have catalytic effect to enhance the conversion rate.

In the flue gas temperature at outlet of air pre-heater, most of SO<sub>3</sub> is still in gaseous condition. However, using high sulfur fuel means that SO<sub>2</sub> concentration is high, and if wet type FGD is equipped in order to meet the requirement to reduce SO<sub>2</sub> emission, the flue gas temperature will be reduced to water saturated condition, and in this gas quenching process, gaseous SO<sub>3</sub> will be combined with water (H<sub>2</sub>O) and liquidized to be sulfuric acid mist (H<sub>2</sub>SO<sub>4</sub>), which is also often called as SO<sub>3</sub> mist. This SO<sub>3</sub> mist is very fine particle whose diameter is under-sub-micron size.

In FGD, gaseous SO<sub>2</sub> is chemically absorbed but SO<sub>3</sub> mist is hardly captured chemically because it is in particulate (liquid) phase. Larger particles can be physically captured in FGD, however SO<sub>3</sub> mist is too fine to be physically captured in FGD, so that such SO<sub>3</sub> mist particles will slip over to FGD outlet. Once SO<sub>3</sub> mist is discharged from stack, under-sub-micron sized particles are very visible, and it is often called as bluish plume. SO<sub>3</sub> is just a small portion of total SO<sub>x</sub> generated from the boiler, but it is so clear to be seen since the number of the particles is very large in accordance with their small diameter, and it causes serious "visual pollution" problem. SO<sub>3</sub> mist emission is recognized as problem also in the viewpoint of opacity and PM<sub>2.5</sub>. Recently, there is discussion that condensibles including SO<sub>3</sub> mist should also be added to total dust, and if condensibles are to be considered as a part of dust, they must be removed to meet the dust emission regulation.

In order to eliminate such  $\text{SO}_3$  mist, WESP installed at downstream of FGD is one of the best solutions. It collects fine particles including  $\text{SO}_3$  mist electrostatically with a very high collecting efficiency. At the same time, other fine particles, such as boiler dust still remaining at FGD outlet and other FGD carrying over particles, are of course also effectively collected in WESP, and the stack plume condition will be much improved.<sup>(1)(2)</sup> Gas flow system with WESP is shown in Fig. 1.

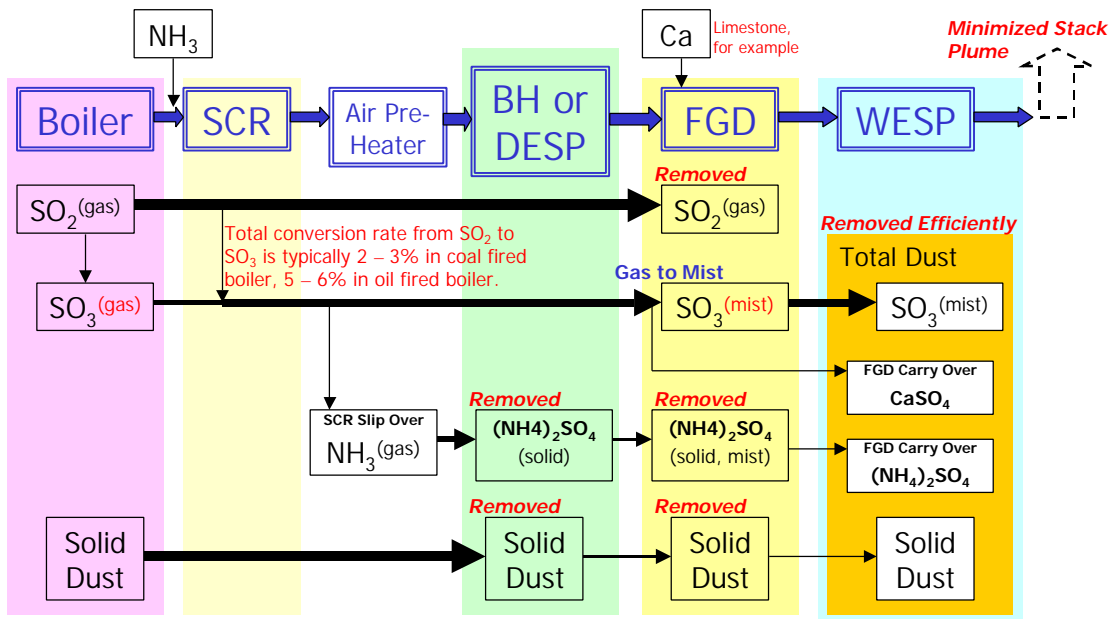


Fig. 1 Gas Flow System and Removal of "Total Dust" including  $\text{SO}_3$  with WESP

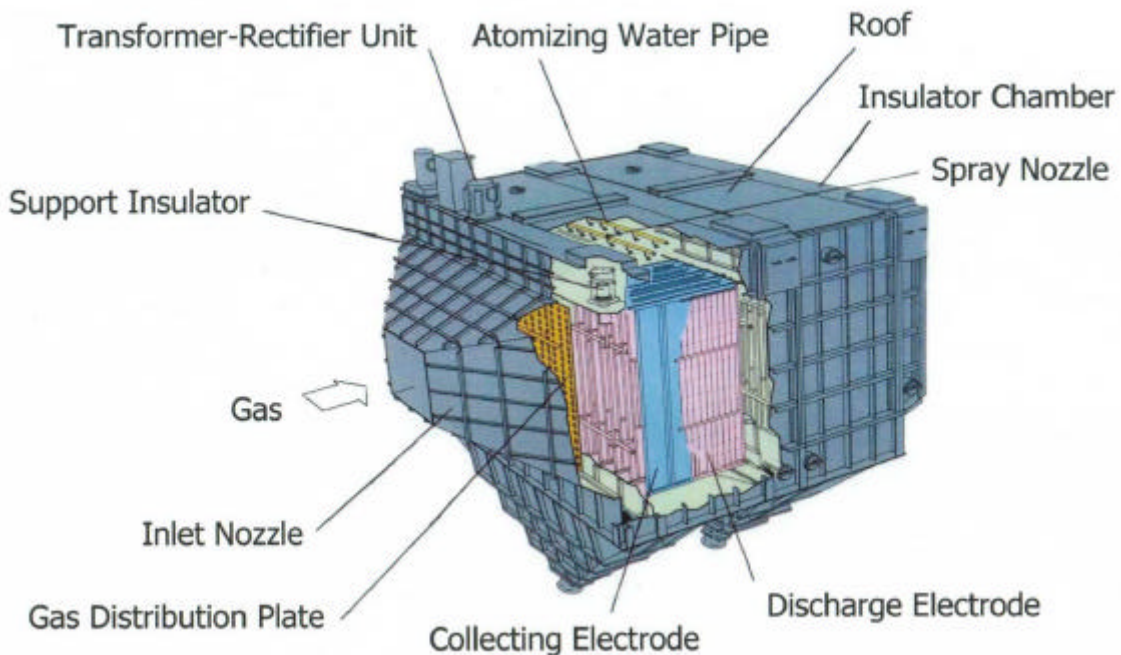


Fig. 2 Basic Structure of Horizontal WESP

## 2. Basic Construction of Horizontal WESP

The basic construction of horizontal WESP is very similar to conventional Dry ESP design as shown in Fig. 2. Flue gas from FGD is introduced horizontally into its casing through inlet nozzle, in which gas distribution plates are installed and the gas velocity is reduced to be uniformly distributed into the main part of the casing, where collecting electrodes are set in parallel along the gas flow direction, and between collecting electrodes, rigid frame type discharge electrodes, which has special geometry with long spikes in order to keep high and stable corona discharge, are equipped.

## 3. Process Flow of Horizontal WESP

### 3.1 Gas Flow

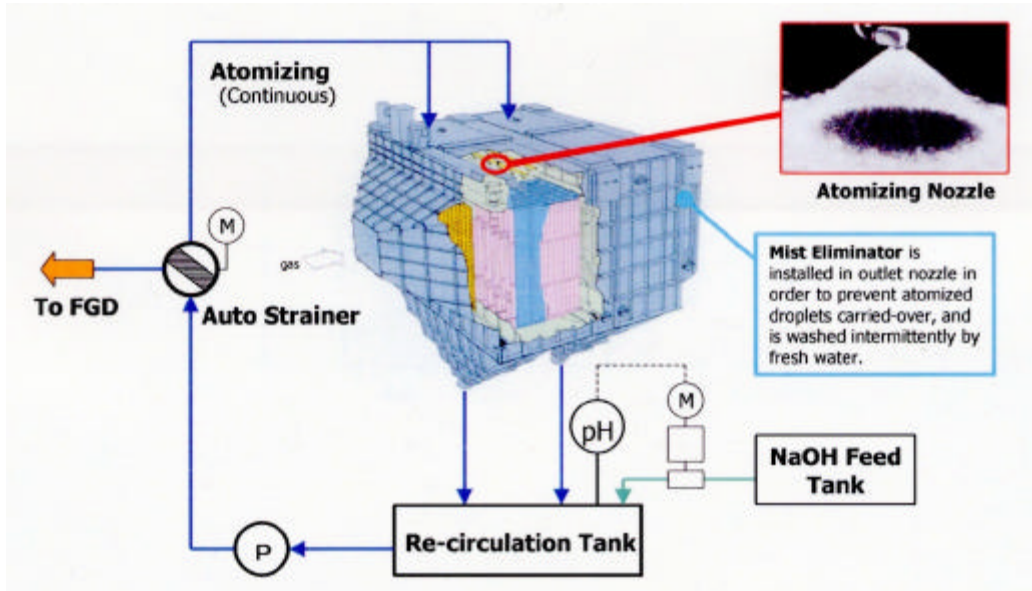
Flue gas from FGD is introduced horizontally into the first section of the collecting zone, where most of the particulate matters contained in the flue gas are collected on the collecting electrode and separated from the gas. Then it flows to the second section, which is independently energized from the first section, and remaining particulate matters are separated also effectively from the gas. If the performance requirement is extremely high, it is possible to install additional sections within the same WESP casing. The purified gas is discharged to downstream through outlet nozzle, where mist eliminator is installed. In the collecting zone, atomized water is continuously supplied and it contains caustic soda (or magnesium hydroxide as an alternative) and its reactants, so that the outlet gas from WESP may have carried over water droplets containing some Na- (or Mg-) reactants, and in order to avoid any influence of such carried over reactants to WESP outlet dust burden, mist eliminator is required. The mist eliminator is washed intermittently by fresh water.

### 3.2 Particulate Matters

Particulate matters, such as fine dust and condensibles including  $\text{SO}_3$  mist, slipped over from FGD, are negatively charged when corona discharge occurs between discharge electrode and collecting electrode, and the electrically charged particles are collected on the surface of the collecting electrodes by electrostatic force (Coulomb force). The collected particulate matters on the collecting electrodes are washed down by atomized water continuously supplied from spray nozzles equipped above electrodes. The washed particulate matters are discharged from hoppers as slurry, and flow into re-circulation tank.

### 3.3 Water Flow

In re-circulation tank, pH of discharged slurry is monitored and it controls the dosing amount of caustic soda (or magnesium hydroxide as an alternative), in order to keep the pH value of water in the tank always beyond the minimum set value (typically  $\text{pH} = 4$ ). Such pH-controlled water is used as atomizing water sprayed in WESP. In order to keep SS (suspended solid) value of atomizing water under certain value (typically  $< 1,000$  ppm), some of the re-circulation flow is extracted from auto strainer to FGD, so that the collected solid dust in WESP is treated finally together with FGD wasting water. Re-circulating water is pumped up to the top of WESP and atomized into the collecting zone of WESP. In this stage, the water is in alkaline side. Atomized water droplets are collected easily on electrodes by electrostatic force because of their larger diameter compared with particulate matters contained in the flue gas, and they form water film flow on the collecting electrodes. Particulate matters collected by electrostatic force are captured in this water film flow, and washed down. Collected  $\text{SO}_3$  mist reduces pH value of water film flow, and it takes the minimum value at the bottom, but it must be still kept beyond the minimum set value in order to avoid sulfuric acid corrosion. For the purpose, pH value of drainage is monitored and controls chemical dosing amount. From the viewpoint of sulfuric acid corrosion, the most critical region is near the boundary part of wet and dry conditions, and completely wet region is less severe in corrosion, because oxygen required for oxidation of material is at the material surface. Continuous atomizing realizes completely wet condition always upon the collecting electrode surface and other metal surface exposed to the gas, and it allows comparatively cost-effective materials such as stainless steel (316L) to be used, instead of higher grade alloy materials.



## 4. Advantages of Horizontal WESP

### 4.1 Continuous Atomizing System with Chemical Additive

Our standard WESP to be applied to collect  $\text{SO}_3$  mist is equipped with continuous atomizing system using re-circulating atomizing water, whose pH is controlled by chemical additive such as caustic soda or magnesium hydroxide. This continuous atomizing system is equipped not only to clean up electrodes but also to protect electrodes from sulfuric acid corrosion, and this is one of the most important key technology. Resin lining can be applied on inner surface of the casing for corrosion protection, however inner parts such as electrodes requires electrical conductivity and it is very difficult to be applied with

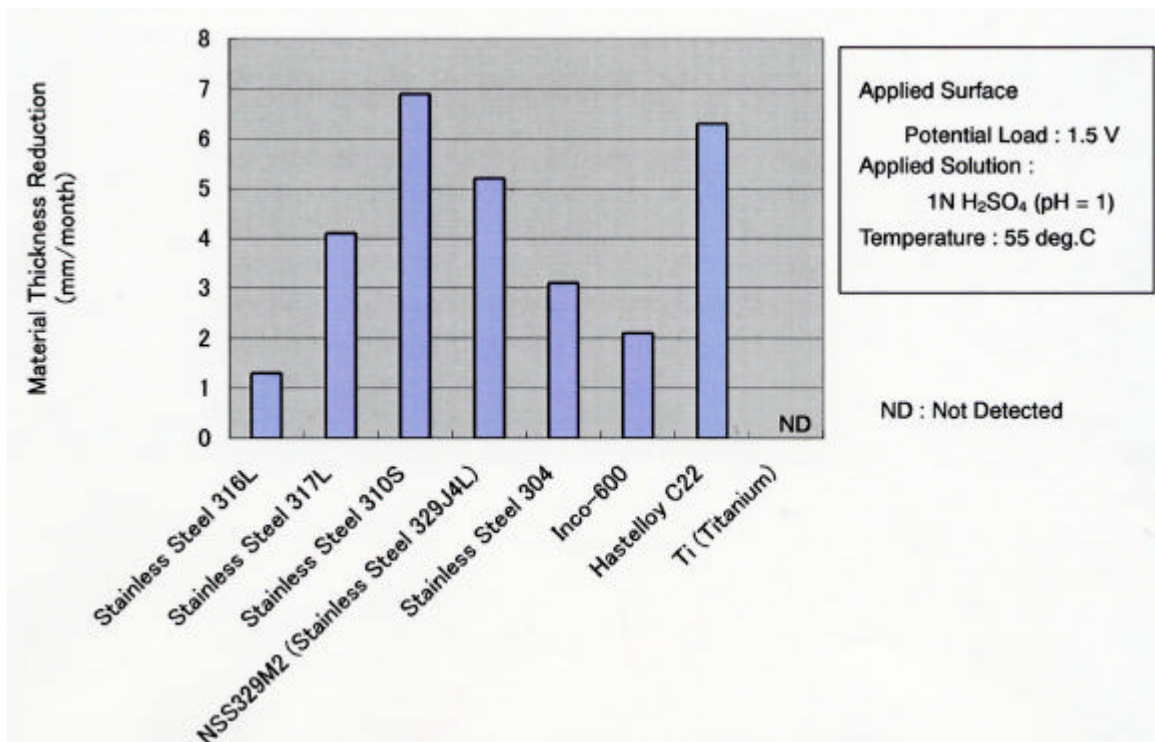


Fig. 4 Corrosion Speed (Material Thickness Reduction)

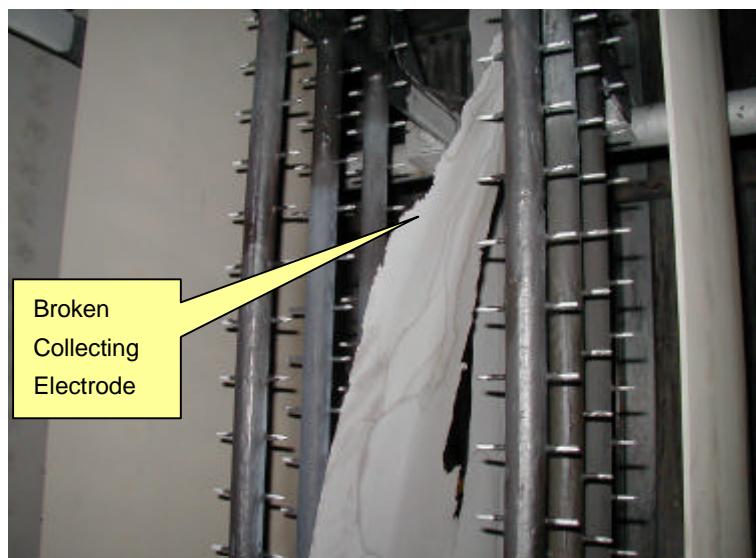
corrosion protector such as resin lining. Continuous atomizing system is judged to be the best way to protect inner parts from sulfuric acid corrosion, through the experience which is met in trying development of periodical washing system, such as follows;

In order to select material of internal parts including electrodes, at first, the corrosion speed of various materials was evaluated in simulated WESP condition by laboratory test, executed in our Takasago R&D Center. It is very important to take surface potential (voltage) load in count to evaluate WESP corrosion, since electrodes of WESP exist in the condition suffered by corona discharge and such surface potential load contributes to accelerate sulfuric acid corrosion. (Any corrosion test ignoring this surface potential load cannot simulate actual corrosion condition in WESP, and very risky to use for evaluation of WESP corrosion.) In the laboratory test, surface potential load of 1.5 V was applied on each test piece, and the test pieces were set in sulfuric acid solution of pH 1, which we thought as enough low pH value at that moment. Summary of the laboratory test is shown in Fig. 4, and it suggests the followings;

- (1) Corrosion speed experienced in energized WESP (with surface potential load of 1.5 V) is completely different from ordinary situations (without considering surface potential load). It is very essential to evaluate WESP corrosion taking surface potential load in count.
- (2) Under the circumstance in WESP (with surface potential load), high grade materials such as Hastelloy or Inconel are not so good from the view point of corrosion protection, and Stainless Steel 316L is rather protective to sulfuric acid corrosion.
- (3) Even Stainless Steel 316L, which is the best among the test data excepting titanium, sulfuric acid corrosion proceeds significantly and plate thickness of 6 mm, for example, can remain less than half a year.
- (4) In this test condition, only Ti (titanium) shows significant result. From test piece of titanium, no thickness reduction can be detected.

In next step, internal parts including electrodes made of titanium were applied to WESP of commercial size, and it was installed in actual industrial boiler plant, and was operated with periodic washing system (without chemical additive). In the plant in which this WESP was installed, SO<sub>3</sub> concentration at WESP inlet was usually around 40 ppm. Titanium material was expected to be used in this situation, however the result completely betrayed the expectation. Only after three months from starting operation, collecting electrode plates made of titanium were broken by sulfuric acid corrosion, and the WESP was not possible to be operated at that time. The situation is shown in Fig. 5.

The reason of the result completely different from the first expectation comes from the fact that the previous assumption of sulfuric acid solution of pH 1 adopted in the laboratory test did not simulate the actual condition. The concentration of sulfuric acid solution on the collecting electrodes of the WESP in Fig. 5 was investigated, and it was found that actual sulfuric acid condition was more severe. SO<sub>3</sub> mist was directly collected on collecting electrode and the concentration of sulfuric acid solution on the collecting electrode became less than 5% (pH = 0) in one hour after the washing, and soon it would furthermore be concentrated to 20 – 40%, which is in the level that cannot be expressed in “pH” value, and very high percentage compared with assumed “pH 1” in the laboratory test, which corresponds to 0.5% sulfuric acid solution.



**Fig 5. Situation of WESP with Internal Parts made of Ti and with Periodic Washing System without Chemical Additive, 3 Months after Starting Operation**

So, even titanium cannot protect the electrodes from sulfuric acid corrosion in WESP with energization and with only periodic washing system, and any other materials such as Hastelloy or Inconel, which are less protective from corrosion in the circumstance with surface potential load, cannot endure. And the continuous atomizing system is concluded to be essential. In large capacity plant of utility power, atomized water amount is huge, so that water consumption will be too much if one-through system without re-circulation line is adopted. In order to keep water consumption in reasonable range, adopting re-circulation line is necessary, and chemical additive, such as caustic soda or magnesium hydroxide, is also required to neutralize sulfuric acid as long as re-circulation line is adopted.

#### 4.2 Advantage of Horizontal Flow WESP

In order to realize the continuous atomizing system, horizontal gas flow type WESP is almost essential. If the continuous atomizing system is adopted in vertical (especially upward) flow type, droplets from completely wet collecting surface will be re-entrained into gas and small droplets will be suspended in the collecting zone. They cause excessive sparks, which decrease the WESP performance, as shown in Fig.6. In the case of horizontal WESP, water film flows down gravitationally and separated from the horizontal gas flow at the bottom part of WESP, so that it allows the continuous atomizing system.

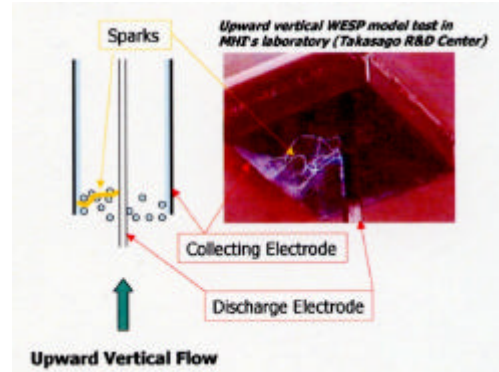


Fig. 6 Vertical WESP Model Test

#### 4.3 Consideration of Space Charge Effect

Horizontal WESP is very easy to realize multi-section WESP, such as two-section type, while vertical Wet ESP must consider water droplets influence coming down from the upper section. Sulfuric acid mist is so fine that corona current is reduced in the first section due to space charge effect, so that multi-section is essential. In order to size WESP properly, the relationship between WESP performance and space charge shall be grasped, and much experience is required for the purpose. Example data of performance reduction curve due to space charge effect is shown in Fig. 7 and Fig. 8. Space charge amount is proportional to sum of total surface area of all particles introduced into WESP per unit time, therefore when particle concentration rise up, particle size becomes finer, and gas velocity is faster, space charge amount becomes larger. When space charge becomes large, corona current is significantly reduced (corona quenching effect) and spark over voltage is reduced (excessive spark over), and as a result, WESP performance will be

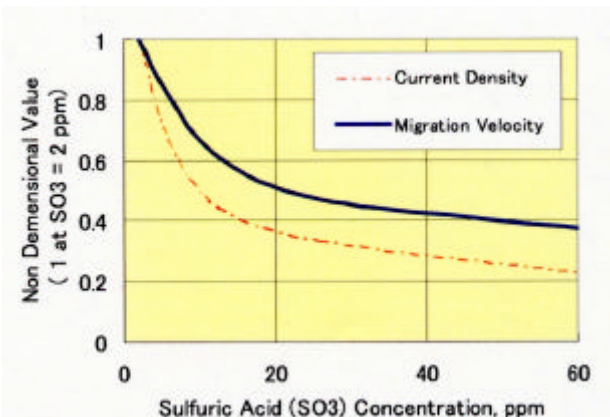


Fig. 7 Performance Reduction Due to Space Charge Effect by High SO<sub>3</sub> Concentration at Typical Gas Velocity Condition

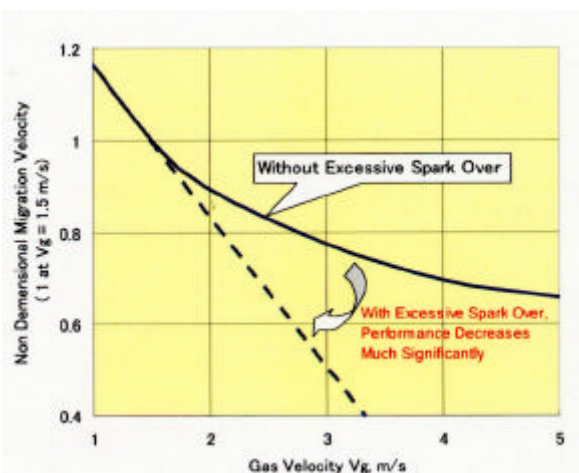
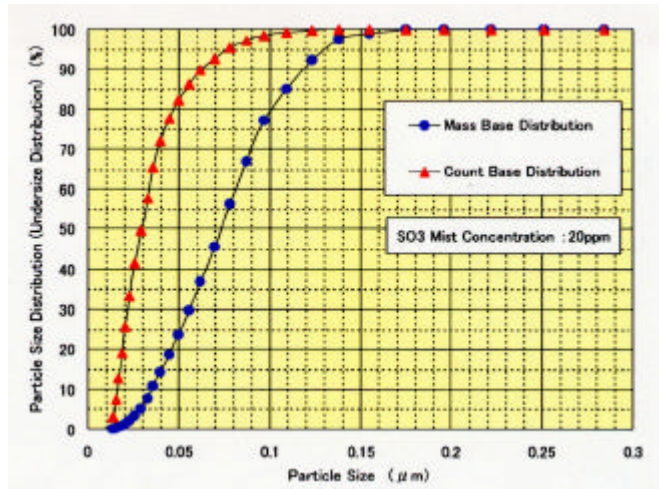


Fig. 8 Performance Reduction Due to Space Charge Effect by High Gas Velocity at Typical SO<sub>3</sub> Concentration Condition

reduced. In the case of this type of WESP installation, small diameter of  $\text{SO}_3$  mist and its concentration are the given conditions, and gas velocity in WESP shall be determined very carefully in order not to reduce the performance too much. Size of  $\text{SO}_3$  mist has been often said as “sub-micron”, however according to our latest measurement in actual plant, diameter of  $\text{SO}_3$  mist ( $d_{50}$ ) is found to be less than 0.08 micron meters even in mass base distribution, and less than 0.04 micron meters in count base distribution. In relation with space charge amount, count base distribution should be taken account, and  $\text{SO}_3$  mist of “under-sub-micron” size, which is 0.03 - 0.04 micron meters, instead of “sub-micron” size, shall be treated in WESP. Such very fine particle size distribution cannot be measured by usual impacting method, and Fig. 9 shows the example of particle size distribution measured in an actual plant ( $\text{SO}_3$  concentration is 20 ppm) by DMA (Differential Mobility Analyzer), which is the particle analyzing method using equipment classifying particles electrostatically, and is possible to analyze even “under-sub-micron” size particles.



**Fig. 9 Particle Size Distribution of  $\text{SO}_3$  Mist Measured by DMA in Actual Plant**

## 5. Commercial Application References of Horizontal WESP

### 5.1 Application in Japan

The first application of horizontal type of WESP installed at downstream of FGD was in 1975, and since then in total 25 plants have been equipped with this type of WESP in Japan.<sup>(2)</sup> Among them, we have experienced many cases of very high sulfuric acid concentration, up to 80ppm. In the very first several projects, the technologies have been established, including those to overcome sulfuric acid corrosion and space charge effect by high sulfuric acid concentration, etc., so that no major trouble has been experienced in this type of WESP since around 1980. Fig. 10 shows the typical case of stack plume elimination, whose  $\text{SO}_3$  concentration is approximately 60 ppm at WESP inlet, and less than 1 ppm achieved at WESP outlet. In this plant, WESP outlet gas is not reheated so that water vapor remains but sulfuric acid mist has been almost completely eliminated.



(a) WESP is “OFF”



(b) WESP is “ON” (only water vapor is seen.)

**Fig. 10 Example of Stack Plume Condition  
(Wet Stack,  $\text{SO}_3$  concentration at FGD outlet is approx. 60 ppm.)**

Among the 25 plants mentioned above, application to Japanese utility power company’s commercially

operated boiler plants are as follows :

Tokyo Electric Power Co. (Japan) / Yokosuka Power Station Unit 1

(265MW, Coal Oil Mixture Fired, operated since 1985)

Chubu Electric Power Co. (Japan) / Hekinan Power Station Unit 1, 2, and 3 <sup>(1)</sup>

(700MW x 3, Coal Fired, operated respectively since 1991, 1992, and 1993)

## 5.2 Application in Europe

In 1997, a horizontal WESP was installed in Werndorf Power Station Unit 2, which is 165MW oil fired boiler, is located near Graz, Austria, and was owned by Austrian utility power company STEWEAG at the time we delivered the WESP. <sup>(3)</sup> (The owner company of the power station has been turned to Verbund nowadays.) This is the first WESP in Europe equipped at downstream of FGD in boiler plant. The purpose of installing this WESP is to eliminate SO<sub>3</sub> mist plume from stack, and it has been and is being operated successfully up to now.

## 6. WESP in Future

As described above, due to the conditions such as high corrosion possibility, high space charge, etc., we are judging that horizontal WESP with continuous atomizing of re-circulation water whose pH is controlled by chemical additive is the most reliable and proven technology to reduce SO<sub>3</sub> from boiler flue gas using high sulfur content fuel. Especially, for large capacity boilers of utility power, there may not exist alternatives with the same grade of reliability. However, this type of WESP is fairly large equipment, and we have also recognized that more compact equipment will be highly preferable, especially considering the requirement for retrofit installation to existing boiler facilities.

As we have already presented <sup>(4)(5)</sup>, we have developed MDDS (Mitsubishi Di-electric Droplet Scrubber), which is a new type WESP adopting completely new concept to capture SO<sub>3</sub> mist electrostatically on large droplets of water. Fig. 11 shows a schematic illustration of MDDS. Flue gas is introduced into pre-charger (PC) and SO<sub>3</sub> mist is negatively charged, and then the gas is introduced into collecting section (CS). The figure shows 2 collecting sections type MDDS and water is sprayed below each CS. This comparatively large sprayed water droplets are introduced together with pre-charged fine particles of dust and SO<sub>3</sub> mist to CS to which external electric field is supplied. Since parallel plate electrodes are used in CS to form equal electric field, comparatively large water droplets generate polarized charge on their surface, and pre-charged fine particles of dust and SO<sub>3</sub> mist are captured on the surface of the water droplets with polarized charge, as shown in Fig. 12. Some of such water droplets capturing fine particles are collected on electrodes in CS, and some remaining will pass through CS but they are comparatively large particles and it is possible to be easily captured in Mist Eliminator installed at the outlet of MDDS. The space between PC and 1st CS can be used as absorber, and the function of FGD (SO<sub>2</sub> absorber) can be integrated with MDDS.

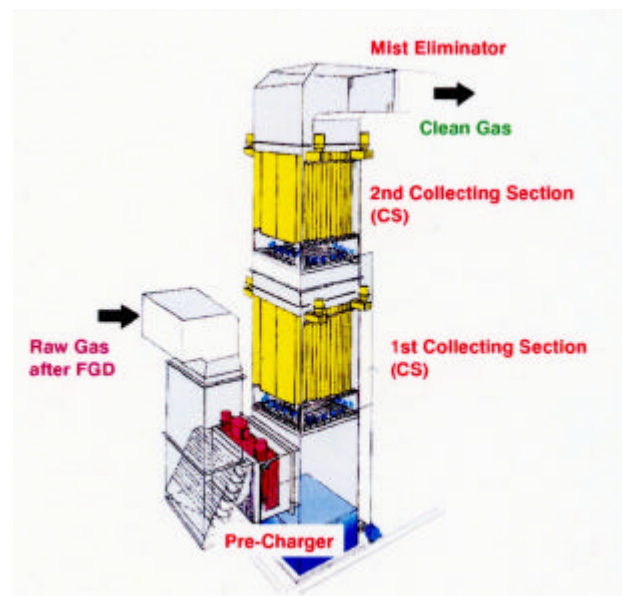


Fig. 11 Example of Structure of MDDS

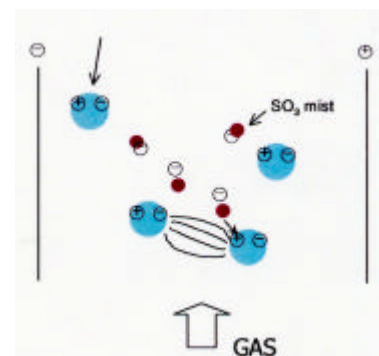


Fig. 12 Pre-charged Particles Captured on Water Droplets with Polarized Charge



At present, four industrial boiler plants in Japan are equipped with MDDS, as shown in Table 1. Example photograph of the commercially operated MDDS is shown in Fig. 13.

MDDS has realized vertical flow WESP and has great advantage in its very small footprint area. However, in this moment, power consumption is comparatively high compared with conventional horizontal WESP for the same planning conditions, and it will be a disadvantage of MDDS especially if it is applied in a large plant. Additionally, due to some structural design limitation, the maximum applicable gas flow rate for MDDS is limited as around 300,000 m<sup>3</sup>N/h(wet). However, we would like to improve MDDS in order to be applicable also in large plants such as boiler plants of utility power in near future.

**Table 1 Commercially Operated MDDS in Japan**

	Gas Flow Rate (m <sup>3</sup> N/h)	SO <sub>3</sub> (ppm)		Dust (mg/m <sup>3</sup> N)		Remarks
		inlet	outlet	inlet	outlet	
A	120,000	1.4	0.1	91.1	1.9	CS: 1 stage
B	160,000	31.9	0.9	51.4	5.3	CS: 2 stages
C	170,000	49.8	0.9	35.0	2.0	CS: 2 stages
D	320,000	25.6	4.4	199.0	33.8	CS: 1 stage

Plant A and D : with FGD function

Plant B and C : without FGD function



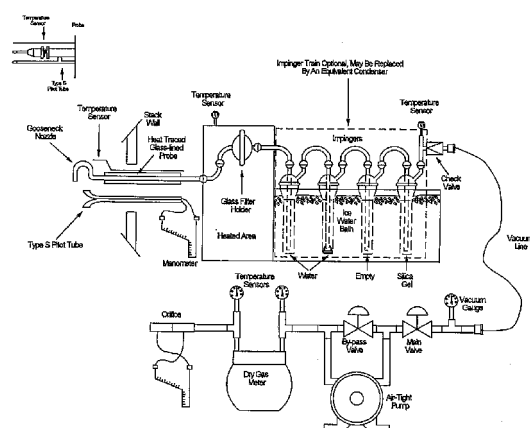
**Fig. 13 Outside View of Commercially Operated MDDS**

## 7. Measuring Method of SO<sub>3</sub>

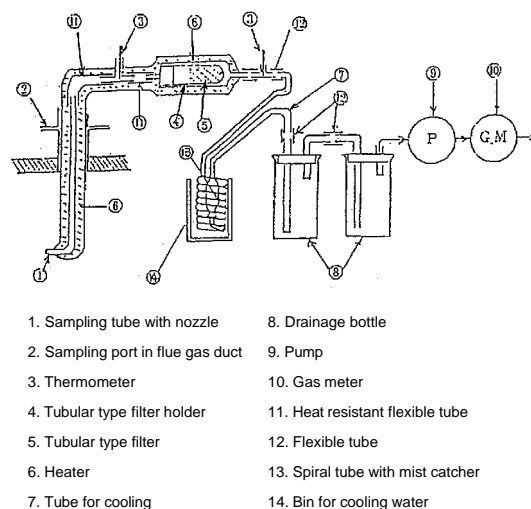
### 7.1 General Situation

Recently, in the United States, requirement for WESP to remove condensibles (condensable particles) including SO<sub>3</sub> mist is increasing. In accordance with the concept of MACT (Most Achievable Control Technology) or BACT (Best Available control Technology), WESP is being recognized as an effective means to reduce condensibles, which should be recognized to be included in “total dust”, and to meet with the requirement for “total dust” reduction in air permission. (The same consideration, that SO<sub>3</sub> mist shall be included in total dust and regulated as a part of dust, is being adopted also in Italy.)

In the United States, the most probably specified measuring method for total dust in this moment may be US EPA Method 5B<sup>(7)</sup> + Method 202<sup>(8)</sup> as shown in Fig. 14, while Japanese most common measuring method is JIS Z 8808<sup>(9)</sup> + Spiral Tube Method as shown in Fig. 15.



**Fig. 14 Typical US Sampling Train for “total dust”  
(US EPA Method 5B + Method 202)**



**Fig. 15 Typical Japanese Sampling Train for “total dust”  
(JIS Z 8808 + Spiral Tube Method)**

Both sampling trains consist of solid dust sampling part with sampling filter, which is commonly used in high temperature dust sampling, for example, at inlet and outlet of dry ESP, and following SO<sub>3</sub> (condensibles) sampling part, which is quite different in US method and Japanese method. In the following clauses, some points to be paid attention in solid dust and SO<sub>3</sub> measurement in wet gas condition. Especially, it is very important to select SO<sub>3</sub> measurement method carefully in order to get accurate measurement value.

## 7.2 Solid Dust Sampling

### 7.2.1 Filter Material

Former part of the both sampling trains is usual measuring method commonly used in dry dust sampling, however when it is adopted in wet gas zone, we must be very careful in absorbing SO<sub>2</sub> and SO<sub>3</sub>. US EPA Method 5B basically follows Method 5<sup>(6)</sup>, and Method 5 specifies the material of the sampling filter as glass fiber. However glass fiber filter is known to absorb SO<sub>2</sub> gas and the absorbing amount is affected also by binder material. Fig. 16 shows

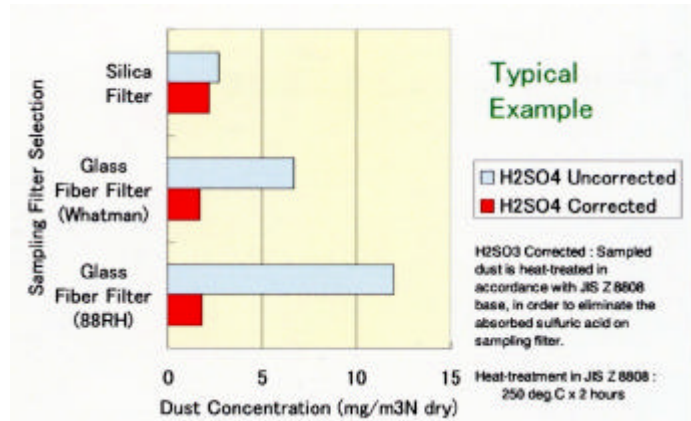


Fig. 16 Influence of SO<sub>2</sub>/SO<sub>3</sub> Gas on Sampling Filter

the typical example of influence of SO<sub>2</sub> or SO<sub>3</sub> gas on sampling filter. Even if the sampling filter is heated, glass fiber filter absorbs SO<sub>2</sub> or SO<sub>3</sub> gas and non heat-treated sample (shown as “H<sub>2</sub>SO<sub>4</sub> uncorrected” in Fig. 16) includes additional value not contributed by solid dust. This influence differs also by binder material, even if the same glass fiber material is used for the filter base media. This influence of SO<sub>2</sub>/SO<sub>3</sub> gas can be eliminated if the sampling filter is heat-treated according to JIS Z 8808 instruction (250 deg. C x 2 hours) as also shown as “H<sub>2</sub>SO<sub>4</sub> corrected” in Fig. 16. However, in order to avoid such influence of SO<sub>2</sub> or SO<sub>3</sub> gas, Silica or Quartz material, which is less affective to SO<sub>2</sub> gas, is highly recommendable to be selected for the sampling filter.

### 7.2.2 Heat-treatment Temperature

Shown in Fig. 16, if the sampling filter is heat treated after the sampling in accordance with JIS Z 8808 instruction, namely 250 deg. C x 2 hours, influence of SO<sub>2</sub> or SO<sub>3</sub> gas may be canceled, however the heat treatment procedure in JIS is different from that specified in US EPA Method 5, which specifies 160 deg. C x 6 hours. We consider that heat-treatment temperature specified in EPA method is not high enough to eliminate SO<sub>3</sub> condensation on filter and to obtain accurate value only of solid dust, due to the result of a laboratory test, in which we prepared sampling filters spiked with sulfuric acid and they are heated with both EPA way (160 deg. C x 6 hours) and JIS way (250 deg. C x 2 hours). We tested spiked amount of sulfuric acid as two conditions such as equivalent to the conditions sampling 30 ppm and 3 ppm of SO<sub>3</sub> in gas. After we treated the filter in 160 deg. C x 6 hours, 7.7% of spiked sulfuric acid equivalent to 30 ppm of SO<sub>3</sub> still remained on the filter and also 3.8% of spiked sulfuric acid equivalent to 3 ppm of SO<sub>3</sub> still remained, while after we treated the filter in 250 deg. C x 2 hours, we could not detect any sulfuric acid remained on the both sampling filters. So, we consider that after-treatment in high temperature such as 250 deg. C is highly recommendable, if accurate value of solid dust concentration should be measured.

## 7.3 Condensibles (SO<sub>3</sub>) Sampling

Condensibles (SO<sub>3</sub>) sampling part is completely different between EPA method and Japanese method. EPA Method 202 specifies to use impingers filled with de-ionized water to absorb condensibles including SO<sub>3</sub>, however it is highly possible that SO<sub>2</sub> gas may be also absorbed in impingers. SO<sub>2</sub> is gas and shall not be included in condensibles, however we cannot distinguish SO<sub>4</sub><sup>2+</sup> detected in impingers coming from SO<sub>2</sub> and coming from SO<sub>3</sub>. EPA Method 202 also specifies N<sub>2</sub> purge after

sampling, however it may not be enough to eliminate the influence of SO<sub>2</sub>. In the condition of WESP outlet, required SO<sub>3</sub> concentration is very low (for example, 2 ppm), and SO<sub>2</sub> concentration is comparatively high (for example, 50 ppm at downstream of FGD), so that the influence of SO<sub>2</sub> may not be ignored.

In Japan, there has not yet been specified official Japanese Industrial Standard to measure condensibles or SO<sub>3</sub>, and we adopt the method so called as Spiral Tube Method. This method is very similar to "Controlled Condensation System" method, which has been established in US as one of the best methods to measure SO<sub>3</sub>/H<sub>2</sub>SO<sub>4</sub> in flue gas in spite of the fact that it has not also been specified as EPA official standard. This method equips "spiral tube" in water bath in sampling train and any SO<sub>3</sub> (gas or mist) will be condensed on the inner surface of the spiral tube when the sampling gas is introduced into the spiral tube. Any SO<sub>2</sub> (gas) cannot be captured in spiral tube because it is not condensed and passes through as gas. From this very simple principal, Spiral Tube Method (or Controlled Condensation System) is considered to give a good measuring value of SO<sub>3</sub>.

We have executed a laboratory test, whose flow line is shown in Fig. 17, in order to compare Spiral Tube Method and US EPA Method 202 and to confirm the measurement error by influence of SO<sub>2</sub> gas in Method 202.

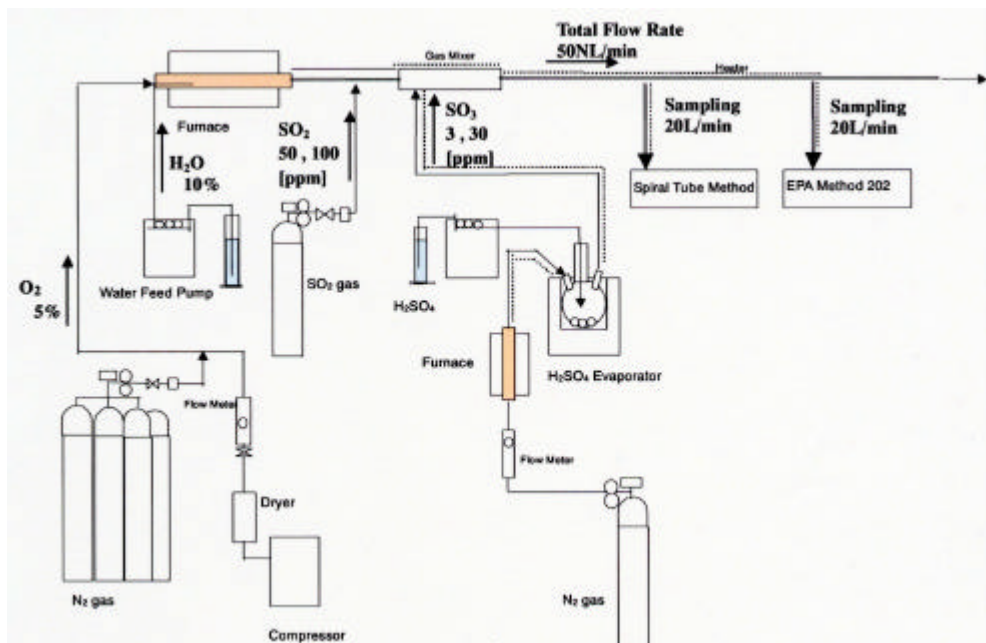


Fig. 17 Flow Line of Laboratory Test for SO<sub>3</sub> Measuring Method Comparison

Table 2 Result of Comparison of SO<sub>3</sub> Measuring Method

Run Number	Prepared Mix Gas		Spiral Tube	Method 202
	SO <sub>2</sub> (ppm)	SO <sub>3</sub> (ppm)	SO <sub>4</sub> <sup>2+</sup> (ppm)	SO <sub>4</sub> <sup>2+</sup> (ppm)
1	50	0	0.2	20
2	50	3 (target)	4.5	24.8
3			3.4	21.6
4			Low SO <sub>3</sub> condition simulating WESP outlet	2.3
5	2.2	9.5		
6	1.7	10.6		
7	50	30 (target)	19.4	35.4
8			18.9	41.9
9			High SO <sub>3</sub> condition simulating WESP inlet	24.0
10	18.7	38.4		
11	30.4	36.0		

Result of the laboratory test is shown in Table 2. It is very difficult to set the “true” SO<sub>3</sub> concentration in prepared gas strictly constant, so that we consider that the measurement value in Spiral Tube Method is within the reasonable fluctuating range, while it is obvious that EPA Method 202 gives too higher value compared with Spiral Tube Method. Even when SO<sub>3</sub> is set as “0” (Run Number 1), 20 ppm of SO<sub>4</sub><sup>2+</sup> is detected from impingers of EPA Method 202, so that it is clear that absorbed SO<sub>2</sub> gas is detected as SO<sub>4</sub><sup>2+</sup> in US EPA Method 202. SO<sub>4</sub><sup>2+</sup> amount detected in EPA Method 202 has no correlation with SO<sub>2</sub> concentration, so that to correct the influence of SO<sub>2</sub> is almost impossible. Therefore, EPA Method 202 is judged to be too risky for the measurement of SO<sub>3</sub> in the condition of WESP inlet and outlet, and Spiral Tube Method (Controlled Condensation System) is highly recommendable to be used for the purpose.

## Summary

- Recently, WESP is recognized as one of the most effective way to remove SO<sub>3</sub> particles from the boiler flue gas using high sulfur content fuel.
- In spite of the technical difficulties due to the sulfuric acid corrosion and high space charge effect in high SO<sub>3</sub> concentration, technology of horizontal WESP with continuous atomizing system has been established, and this is the best solution of SO<sub>3</sub> removal especially for large capacity boilers such as those for utility power.
- Also MDDS (vertical WESP) is being successfully used for SO<sub>3</sub> removal in industrial boiler plants.
- Measuring method of solid dust and SO<sub>3</sub> is very important and should be carefully selected in the conditions at WESP inlet and outlet.

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